Defense Technical Information Center Compilation Part Notice

ADP012307

TITLE: Spontaneous AC Field Induced Mechanical Rotation in Magnetostrictive FeSiB-Based Wires Subjected to Thermal Treatments

DISTRIBUTION: Approved for public release, distribution unlimited

This paper is part of the following report:

TITLE: Applications of Ferromagnetic and Optical Materials, Storage and Magnetoelectronics: Symposia Held in San Francisco, California, U.S.A. on April 16-20, 2001

To order the complete compilation report, use: ADA402512

The component part is provided here to allow users access to individually authored sections of proceedings, annals, symposia, etc. However, the component should be considered within the context of the overall compilation report and not as a stand-alone technical report.

The following component part numbers comprise the compilation report:
ADP012260 thru ADP012329

UNCLASSIFIED

Mat. Res. Soc. Symp. Proc. Vol. 674 © 2001 Materials Research Society

SPONTANEOUS AC FIELD INDUCED MECHANICAL ROTATION IN MAGNETOSTRICTIVE FeSiB-BASED WIRES SUBJECTED TO THERMAL TREATMENTS

V.Raposo[1,2], A.Mitra[1,3] and M.Vázquez[1]

[1] Instituto de Ciencia de Materiales de Madrid, CSIC, 28049 Cantoblanco, Madrid, Spain
[2]Dpto. Física Aplicada, Universidad de Salamanca, 37008 Salamanca, Spain
[3]National Metallurgical Laboratory, Jamshedpur, India

ABSTRACT

An astonishing new phenomenon has been recently observed in magnetic wires. It consists of the spontaneous rotation of the wires when submitted to an exciting AC axial field with frequency of the order of kHz and amplitude above some threshold. The rotation is believed to appear due to interaction between generated magnetoelastic standing waves and induced eddy currents. In the present work rotational characteristics of $Fe_{77.5}Si_{7.5}B_{15}$ and $Fe_{73.5}Si_{13.5}B_9Cu_1Nb_3$ wires in their as-cast amorphous state and after heat treatments leading to devitrification has been investigated. It is proved that this rotational phenomenon is only observed in samples with large enough magnetostriction irrespective of their structural character. Moreover, changes in rotational characteristics are ascribed to the structural modifications accompanying the devitrification process.

INTRODUCTION

The mechanical rotation of Fe base amorphous wires with bistable magnetic behavior when subjected to an alternating AC field of several kHz has been recently reported [1-3]. Rotational wire frequencies oscillate around tens of Hz. Wire rotation frequency depends on magnetostriction constant, and it has been observed for both positive and negative values as shown in [2]. The influence of the length of the wire in the excitation frequency that causes a rotation and the appearance of rotation at higher harmonics of some fundamental frequencies reveals the existence of a resonant magnetoelastic standing wave in intimate correlation with the origin of the rotation. This phenomenon has been proved to have potential applications in different fields such as in micro-motors or viscosimetry [4,5].

Although a quantitative theory is not currently available, our results show that this is a general property of materials with high magnetostriction constant, no matter their crystalline structure, since it is present in amorphous but also in polycrystalline wires, as recently reported [6]. Consequently, the rotational behavior is nowadays expected to be determined neither by the alloy composition, nor by the structural nature of the material, nor by the domain structure, but seemingly by the magnetostrictive character of the sample.

The aim of this work has been to study the AC field induced rotation of $Fe_{77.5}Si_{7.5}B_{15}$ and $Fe_{73.5}Si_{13.5}B_9Cu_1Nb_3$ amorphous wires exhibiting large magnetostriction in their as-cast state and after annealing that finally results in the devitrification of the samples [7]. In fact, in the case of $Fe_{73.5}Si_{13.5}B_9Cu_1Nb_3$ wires, annealing leads to homogeneous and stable partial crystallization with noticeable reduction of magnetostriction and disappearance of that phenomenon.

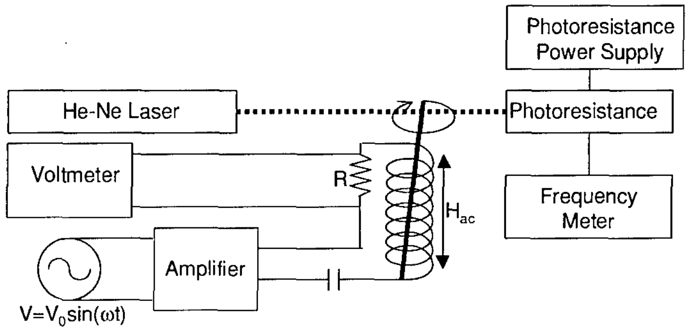

Figure 1. Schematic block diagram of the measuring set-up

EXPERIMENTAL TECHNIQUES

$Fe_{77.5}Si_{7.5}B_{15}$ and $Fe_{73.5}Si_{13.5}B_9Cu_1Nb_3$ amorphous wires have been prepared at the laboratory by in-rotating-water quenching-technique. The diameter of the wires was 120μm and pieces about 50 mm in length were taken for the AC field induced rotation experiments. The experimental set-up for measuring the rotation frequency of the wire is shown schematically in Figure 1. The wire was placed inside a 40 mm long solenoid generating an axial magnetic field (constant of $125Am^{-1}/A$). The solenoid was fed by a current to produce axial AC magnetic field by a function generator (model HM 8030-5) coupled with an amplifier. A thin glass tube of 4 mm in diameter was placed inside the coil and its bottom was sealed with a flat glass piece. Thus, the wire rotates freely leaning on its bottom end in a vertical position. The frequency of the applied axial AC magnetic field ranged from 1 kHz to 35 kHz. The rotational speed of the wires was measured by the interception of a laser beam, which was directed towards a detector (photoresistance) connected to a frequency meter. The measured frequency actually showed double value of the real frequency of rotation since the interception with the laser beam was twice that of a complete rotation of the wire.

Magnetic hysteresis loops of the samples used for rotational experiments were measured using a conventional low-frequency induction technique.

Isochronal (30 min.) thermal treatments were performed in a conventional Joule heated furnace under argon atmosphere for a range of annealing temperatures up to 650ºC.

DISCUSSION OF RESULTS

Hysteresis loops of the as-cast and annealed wires of $Fe_{77.5}Si_{7.5}B_{15}$ and $Fe_{73.5}Si_{13.5}B_9Cu_1Nb_3$ are presented in Figures 2 and 3, respectively. As it can be seen, as-cast wires of both compositions do not present the usual bistable squared loops due to their short length (50 mm), smaller than the closure domain structures formed at the ends of the wires to reduce the magnetostratic energy [8]. As annealing temperature is increased the samples loose completely the large Barkhausen jumps due to the relaxation of internal stresses. After annealing at 540ºC the $Fe_{77.5}Si_{7.5}B_{15}$ sample looses the amorphous structure (Fe_3Si and Fe_2B grains segregate) and its soft magnetic properties (coercive field increases up to 65 Oe).

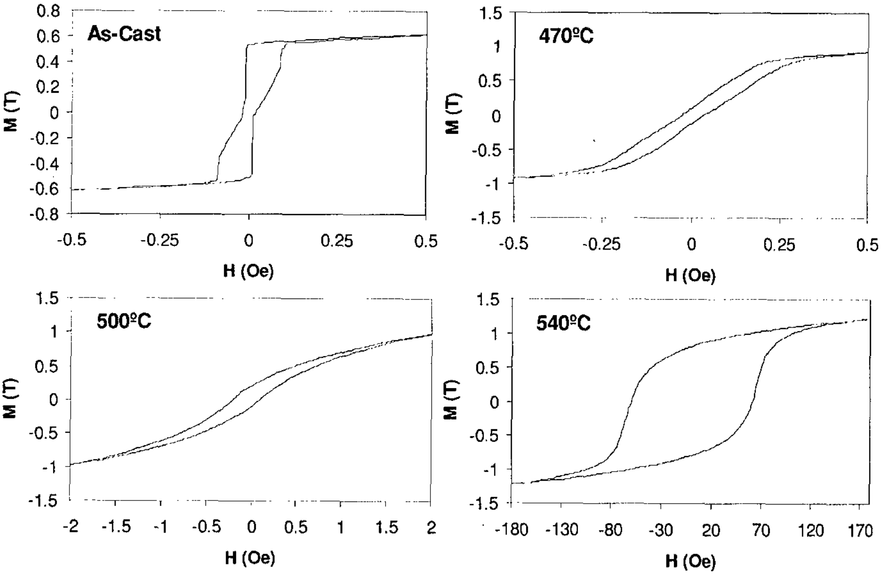

Figure 2. Hysteresis loops for the As-Cast and annealed $Fe_{77.5}Si_{7.5}B_{15}$ wires.

In the case of $Fe_{73.5}Si_{13.5}B_9Cu_1Nb_3$ wires, α-FeSi nanograins (around 10 nm average grain size) segregate after treatment at 540ºC. The devitrification process goes further with increasing the annealing temperature resulting in grain size increase and appearance of new phases (i.e. Fe_2B). In particular, after annealing at 650ºC a magnetic hardening is observed similar to that obtained annealing at 540ºC for the $Fe_{77.5}Si_{7.5}B_{15}$ wire.

Figure 4 shows the $Fe_{77.5}Si_{7.5}B_{15}$ wire rotation frequency as a function of the exciting field frequency for a constant AC field amplitude of 90 Oe for as-cast and annealed wires. Rotation of the as-cast wire is found at certain characteristic frequencies of the applied field and at their higher harmonics. Figure 5 shows the corresponding spectra for the $Fe_{73.5}Si_{13.5}B_9Cu_1Nb_3$ wires at the same AC field amplitude.

To determine the characteristic fundamental frequencies at which rotation takes place, the experimental data have been fitted to a superposition of Gaussian distributions, *y(t)*, around the characteristic frequencies as:

$$y(f) = \sum_{i=1}^{N}\sum_{j=1}^{4} A_{ij}(f)\exp\left[-\sigma(f - jF_i)^2\right] \qquad (1)$$

where F_i are the characteristic frequencies, σ is related to the width of the Gaussian distribution N is the number of fundamental frequencies and $A_{ij}(f)$ is an amplitude parameter that depends on the field amplitude. The index j denotes the corresponding harmonic number. For the $Fe_{77.5}Si_{7.5}B_{15}$ wires there are two fundamental frequencies, but for the $Fe_{73.5}Si_{13.5}B_9Cu_1Nb_3$ wires up to four frequencies are needed to characterize the spectra. As shown in Figures 4 and 5 the rotation is observed not only at one frequency, but also in a narrow frequency range around these fundamental ones with a Gaussian-like shape.

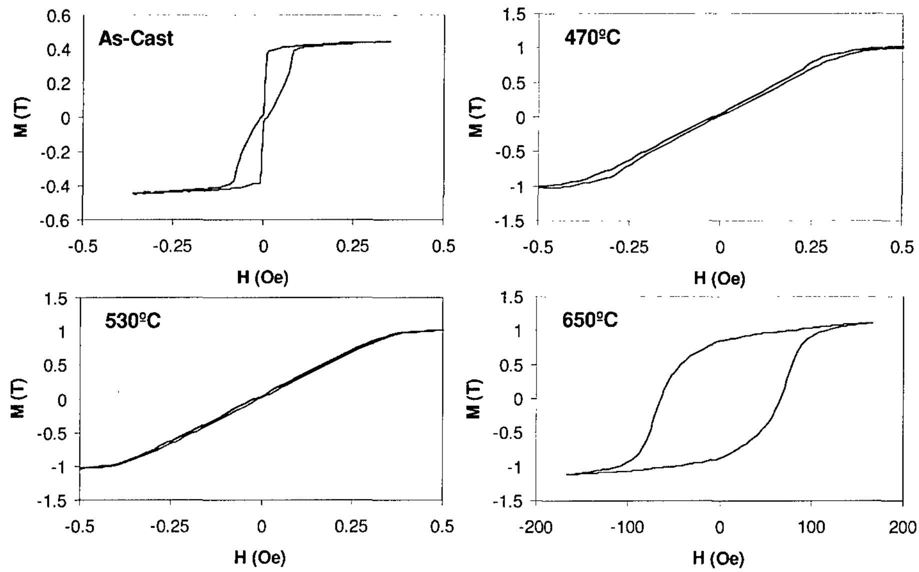

Figure 3. Hysteresis loops for the As-Cast and annealed $Fe_{73.5}Si_{13.5}B_9Cu_1Nb_3$ wires.

In spite of the complex spectra (see Figure 4), the higher harmonics of a set of fundamental frequencies can be extracted. The number N of fundamental frequencies found for $Fe_{77.5}Si_{7.5}B_{15}$ and $Fe_{73.5}Si_{13.5}B_9Cu_1Nb_3$ samples is 2 and 4, respectively. In the $Fe_{77.5}Si_{7.5}B_{15}$ wire for all the annealing temperatures there are two fundamental modes around 5 and 8 kHz, being the one at 5 kHz quite wide. Only the devitrified sample has a very different spectra with reduced number of modes and frequencies of rotation. Also, an increase of the wire rotation frequency with exciting frequency can be observed. This result supports the idea that the rotation is caused by the coupling of the eddy currents induced in the wire when there is a magnetolastic resonance. As frequency is increased so are the induced currents, and accordingly the Lorentz force. This force is not canceled due to the lack of perfect symmetry in the system, as the wire is standing in a non-uniform alternating magnetic field. In $Fe_{77.5}Si_{7.5}B_{15}$ samples, the changes in magnetostriction constant are negligible during structural relaxation [9]. This fact explains the quite similar spectra of wire rotation frequency for all the samples. The differences in the 540ºC annealed sample can be explained by the crystallization and the induced magnetic hardening.

This is in contrast with the results obtained for the $Fe_{73.5}Si_{13.5}B_9Cu_1Nb_3$ wires. In these wires, annealing results in intermediate devitrification and quite large change in the magnetostriction constant [10]. This change modifies the rotational spectra of the wires as shown in Figure 5. Fundamental frequencies found in the as-cast state (4.7, 7.5, 10.8 and 12.5 kHz) shift with annealing and eventually, after treatment at 550ºC rotation disappears. This temperature corresponds to the optimum soft magnetic properties when the lowest magnetostriction value is achieved. Rotation is observed again upon a new increase of magnetostriction with further crystallization (e.g. anneealing at 650ºC).

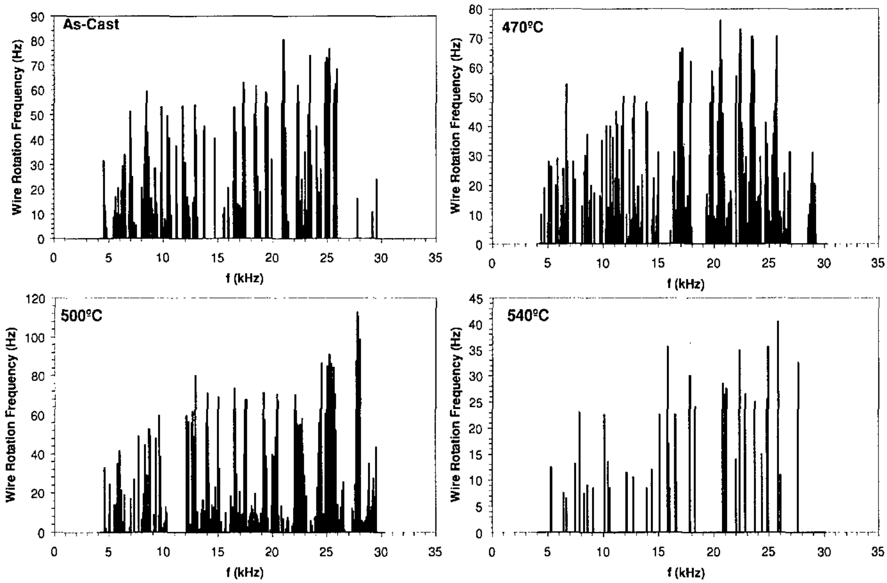

Figure 4. Rotational spectrum (wire frequency vs exciting field frequency) for the as-cast $\boldsymbol{Fe_{77.5}Si_{7.5}B_{15}}$ *wire and after annealing at different temperatures as indicated.*

All these results show that AC field induced rotation has its physical origin in the magnetoelastic resonance, which is more important as magnetostriction constant is increased. This parameter can be tailored in some compositions as the $Fe_{73.5}Si_{13.5}B_9Cu_1Nb_3$.

CONCLUSSIONS

A new effect consisting of the AC field induced mechanical rotation has been studied in $Fe_{77.5}Si_{7.5}B_{15}$ and $Fe_{73.5}Si_{13.5}B_9Cu_1Nb_3$ wires subjected to thermal treatments that modify their structural nature. In the case of the $Fe_{77.5}Si_{7.5}B_{15}$ wire, rotational characteristics are almost unchanged by annealing, at least until crystallization is achieved, which is ascribed to the fact that the magnetostriction constant does not change significantly. In contrast, $Fe_{73.5}Si_{13.5}B_9Cu_1Nb_3$ wires undergo noticeable changes of magnetostriction before full crystallization. Rotational characteristics are determined most importantly by magnetostriction but are also modified by the structural nature and the degree of magnetic softness. The influence of exciting AC frequency also supports the assumption that the rotation is caused by the coupling of the induced eddy currents with the non-uniform magnetic field that exist in the coil. In short, for this phenomenon to be observed, magnetically soft materials are required but exhibiting large enough magnetostriction.

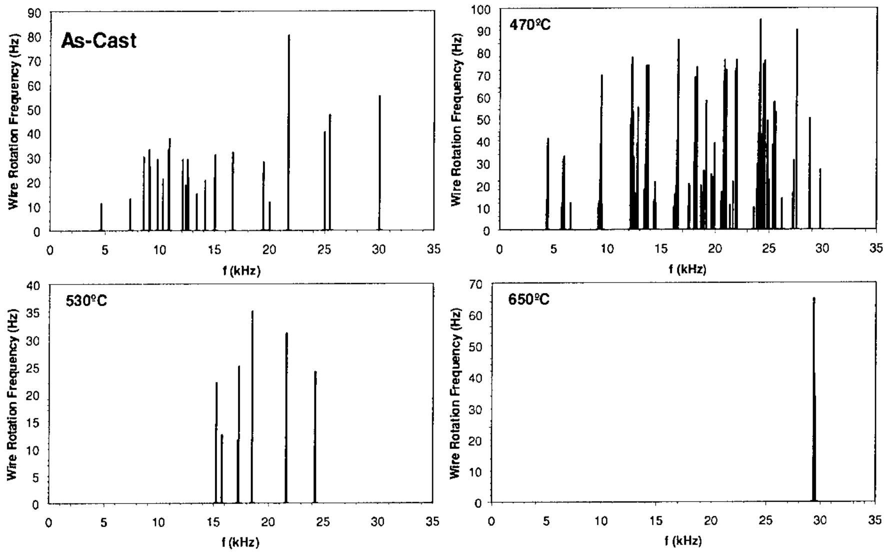

Figure 5. *Rotational spectrum (wire frequency vs exciting field frequency) for the as-cast* $Fe_{73.5}Si_{13.5}B_9Cu_1Nb_3$ *wire and after annealing at different temperatures as indicated.*

ACKNOWLEDGEMENTS

The work has been supported by the Spanish CICYT under projects MAT 98-0965 and MAT 99-0422. V. Raposo wishes to thank the Comunidad Autónoma de Madrid for his grant under project CAM 07N/0033/98.

REFERENCES

1. H. Chiriac, C.S. Marinescu, and T.-A. Ovári, IEEE Trans. Magn. 33 (1997) 3349.
2. F.J. Castaño, M. Vázquez, D.-X. Chen, M.Tena, C. Prados, E. Pina, A. Hernando, and G. Rivero, Appl. Phys. Lett. 75 (1999) 2117.
3. H. Chiriac, T.-A. Ovári and C.S. Marinescu, J. Magn. Magn. Mat. 215-216 (2000) 413.
4. F.J. Castaño, M. Vázquez, T.-A. Óvári, D.-X. Chen, and A. Hernando, IEEE Trans. Magn. 36 (2000) 2791.
5. M. Vázquez, F. J. Castaño, T.-A. Óvári, V. Raposo, and A. Hernando, Sensors and Actuators A. 2934 (2001) (in press)
6. V. Raposo, T.A. Óvári and M. Vázquez , IEEE Trans. Magn. (in press, issue July 2001)
7. P. Marín, M. Vázquez, A.O. Olofinjana and H.A. Davies, Nanotructured Materials 10 (1998) 299.
8. M. Vázquez and D.-X. Chen, IEEE Trans. Magn. 31 (1995) 1229.
9. A. Hernando and M. Vázquez, in "Rapidly solidified alloys" (ed. H.H. Liebermann), Marcel Dekker, Inc. New York, 1993 p. 553-590.
10. G. Herzer, "Nanocrystalline Soft Magnetic Alloys", Handbook of Magnetic Materials, Vol.10 (ed. K.H.J Buschow), Elsevier Science B.V. 1997, p 417-461.